Relative Importance of Repair Material Properties
Then and Now

Jim McDonald
McDonald Consulting
Clinton, MS
jmcdonald14@comcast.net

ICRI Convention
Fall 2013
A Look Back
Fort Peck Spillway - 1938
Melvin Price Lock and Dam
536 dams and 260 lock chambers; 60% were over 20 years age; >40% were over 30 years age; and ~50% would reach 50-year design life by 2000.
Severe Exposure Conditions
Repair Material Performance

“Selecting Repair Materials”

“Some Important Material Properties That Should Be Considered”

By James Warner
Consulting Engineer
Mariposa, California

Concrete Construction
October 1984

Repair Material Considerations

“While both bond and compressive strength values are frequently provided by material suppliers, characteristics such as the material’s dimensional stability, stiffness and capability of transmitting fluids, vapors and electrical current can be of equal or greater importance.”

“To match properties of the base concrete as closely as possible, portland cement concrete or similar cementitious compositions are frequently the best choices for the repair material. But not always.”

“Once the criteria are known, it will often be found that more than one material can be used with equally good results. Final selection of the material or combination of materials must then take into account the ease of application, cost, and available labor skills and equipment.”

(From Warner, 1984)
Choosing A Repair Material
Application and Service Conditions

- Repair thickness, orientation?
- Moisture, temperature, available ventilation?
- Available downtime?
- Chemical attack?
- Heavy traffic?
- Bond to steel & concrete?
- Service temperature range?
- Exposure to vibration?
- Appearance important?
- Desired service life?

(After Warner, 1984)
## General Requirements for Repair Materials (1980’s)

<table>
<thead>
<tr>
<th>Property</th>
<th>Relationship of Repair Material (R) to Concrete Substrate (C)</th>
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<td>Slant-Shear Bond</td>
<td>R &gt; C</td>
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<tr>
<td>Modulus of Elasticity</td>
<td>R ≥ C</td>
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<tr>
<td>Thermal Expansion/Contraction</td>
<td>R ≤ C</td>
</tr>
<tr>
<td>Unrestrained Shrinkage</td>
<td>R = C</td>
</tr>
</tbody>
</table>
Where can we obtain additional repair guidance/information?

International Concrete Repair Specialists
Naperville, IL May 1988
Typical Lock Wall Rehabilitation

EL 543

Upper Pool

Concrete Removal & Replacement Varies 12” to 24”

EL 503

Low Pool

Varies 12” to 24”
Deteriorated Concrete Removal

Secondary

Primary
Surface Preparation
Cast-In-Place Concrete
Concrete Cracking
Lock Wall Rehabilitation
Restrained Contraction
Effect of Restrained Contraction

Overlay Cracking

New Construction No Cracking
Brandon Road Dam
Bond Breaker Eliminated Cracking

Bond Breaker
Precast Vs. CIP

Troy Lock

- Advantages of Precasting
  - Minimal cracking
  - Durability
  - Speed of construction
  - Reduced maintenance
  - Minimizes weather impact
  - Economy ($5/ft^2 < CIP)

- References
  - TR REMR-CS-41
  - REMR-CS-4 (Video)
Effect of Restrained Contraction

Small Repairs
Shrinkage Test Results

Repair Materials

- Low Shrinkage
- Moderate Shrinkage
- High Shrinkage

Increased tendency to crack

After Gurjar & Carter (1987)
US Army Corps of Engineers
Waterways Experiment Station


Repair, Evaluation, Maintenance, and Rehabilitation Research Program

Results of Laboratory Tests on Materials for Thin Repair of Concrete Surfaces
Drying Shrinkage Test Results

28 Days

Strain, %

Concrete Control

Repair Materials

After REMR CS-52(1997)
Objective: Composite Repair

A repair produced by combining different materials (e.g., concrete substrate, bonding agent, and repair material) which are so interconnected that the combined components act together as a single unit.
Performance Criteria
Cement-Based Materials

12 Repair Materials

Field Performance Tests

Laboratory Tests

Correlation

Dimensional Compatibility
Performance Criteria

Laboratory Tests

- Drying Shrinkage
  - Unrestrained
  - Restrained
- Modulus of elasticity
- Thermal expansion
- Strength
Performance Criteria

Field Tests

- 3 exposure sites (FL, IL, & AZ)
- 3 repairs with each of the 12 materials
- Conduct restrained shrinkage tests
- Monitor performance
Field Exposure Tests

Relative Performance Ratings

6 - Satisfactory
2 - Marginal
4 - Unsatisfactory
Drying Shrinkage
50% RH, 28-Days Age

Material numbers

Shrinkage, millionths

Cementitious
Polymer Modified

Material numbers

1 2 3 4 5 6 7 8 9 10 11 12
28-Day Shrinkage & Field Performance

Acceptable Materials

Strain, %

Relative field ranking

![Graph showing the relationship between strain and field ranking.](#)
Restrained Drying Shrinkage

Ring Test
10 of 12 Cracked

Criteria
No cracking <14 days age
0.10% max implied strain
Restrained Shrinkage Test
ASTM C1581-04
Tensile Strength Test Results
28-Days Age

Range: 90-740 psi
Average: 390 psi
Overall Tensile Strength and Field Performance

Tensile strength, psi vs. Relative field ranking
Tensile Strength & Field Performance

Marginal and Unsatisfactory Materials

- CRD-C 164

Diameter: 2 in. min
L/D 2.0 - 2.5

Tensile strength, psi

Relative field ranking
Modulus & Field Performance

Relative field ranking vs Modulus of elasticity, psi x 10^6
Overall Coefficient of Expansion and Field Performance

Coefficient, millionths / °F

Relative field ranking

Graph showing the relationship between Coefficient and Relative field ranking.
Compressive Strength and Field Performance

Average: 6,940 psi

If a little is good, then more is not a lot better
Typical Surface Repair

Settlement

Surface Crazing and Cracking

Poor Bond
Concrete Slab

Will A Repair In This Column Carry Any Significant Loads?

No, unless …
Interstates 30 & 45
Dallas, TX
# Performance Criteria for Cement-Based Repair Materials

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength, min</td>
<td>CRD-C164</td>
<td>400 psi</td>
</tr>
<tr>
<td>Modulus of elasticity, max</td>
<td>ASTM C469</td>
<td>$3.5 \times 10^6$ psi</td>
</tr>
<tr>
<td>Thermal coefficient, max</td>
<td>CRD-C39</td>
<td>7 millionths/ °F</td>
</tr>
<tr>
<td>Drying shrinkage, max</td>
<td>ASTM C157 (Modified)</td>
<td></td>
</tr>
<tr>
<td>28 days</td>
<td></td>
<td>0.04%</td>
</tr>
<tr>
<td>1 year</td>
<td></td>
<td>0.10%</td>
</tr>
<tr>
<td>Restrained shrinkage</td>
<td>Ring Method</td>
<td>None &lt; 14 days</td>
</tr>
<tr>
<td>Cracks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implied strain (1 yr.), max</td>
<td></td>
<td>0.10%</td>
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</table>

Laboratory/Field Correlation

Satisfactory Performance

<table>
<thead>
<tr>
<th>Field Rank</th>
<th>Mat'l No.</th>
<th>Tensile Strength, (&gt;400)</th>
<th>Modulus of Elasticity (&lt;3.5)</th>
<th>Thermal Coefficient (&lt;7)</th>
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<th>Thermal Coefficient</th>
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<th>Drying Shrinkage 28 Days (&lt;0.04)</th>
<th>Drying Shrinkage Peak (&lt;0.10)</th>
<th>Ring Test 1st Crack (&gt;)14</th>
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<th>Ring Test 1st Crack (&lt;14)</th>
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<tr>
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<td>2.8</td>
<td>5.8</td>
<td>0.018</td>
<td>0.037</td>
<td>6</td>
<td>0.067</td>
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<td>1</td>
<td>4</td>
<td>348</td>
<td>3.8</td>
<td>8.3</td>
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<td>0.070</td>
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<td>7.6</td>
<td>0.034</td>
<td>0.064</td>
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<td>4</td>
<td>12</td>
<td>742</td>
<td>3.0</td>
<td>9.3</td>
<td>0.029</td>
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<td>None</td>
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#### Satisfactory Performance

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<th>Thermal Expansion Coefficient, (&lt;7)</th>
<th>Drying Shrinkage, 28 Days (&lt;=0.04), Peak, 1&lt;sup&gt;st&lt;/sup&gt; Crack (&gt;=14)</th>
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# Conventional Concrete
# Laboratory/Field Correlation

## 4 Top-Ranked Materials


[http://acwc.sdp.sirsi.net/client/search/asset/1004732](http://acwc.sdp.sirsi.net/client/search/asset/1004732)

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<th>Ring Test Implied Strain, (&lt;0.10)</th>
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**Top 4 materials – 15 of 16 shrinkage compliance, 94%**

**Remaining materials – 18 of 32 compliance, 54%**
Minimizing Shrinkage Cracking

- Decrease water content
- Decrease paste volume
- Increase coarse aggregate
- Shrinkage-reducing admixtures
- Synthetic fibers
- Crack resistant cement

After PCA (2002)
Effect of MSA on Water Content

After PCA (2002)
Effect of MSA on Cement Content

Cement Content, lb/yd³

Non-air-entrained concrete

Air-entrained concrete

Nominal Maximum Size Aggregate, in.

3-in. slump w/c = 0.54

After PCA (2002)
Drying Shrinkage
Effect of 3/4-in. Aggregate

<table>
<thead>
<tr>
<th>Time, days</th>
<th>Concrete</th>
<th>Mortar</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>200</td>
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<td>400</td>
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<tr>
<td>300</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>400</td>
<td>500</td>
<td>600</td>
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</table>

> 70% reduction
Paste Volume vs Shrinkage

Shrinkage strain, %

0.3 0.4 0.5 0.6 0.7 0.8

0
0.04
0.08
0.12
0.16

40% Paste

30% Paste

20% Paste

After Nawy (1996)
Effect of Aggregate Volume on Drying Shrinkage

After Price (2002)

<table>
<thead>
<tr>
<th>Aggregate Volume, %</th>
<th>Shrinkage strain, %</th>
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$R^2 = 0.7103$

After Price (2002)
Looking Back
1980s

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- Nonstandard or modified test methods
- No protocol for testing and reporting information
- Lack of performance criteria
“We Have Come A Long Way”
“We Have Come A Long Way”
ICRI Bookstore
Free Download

Standardized protocol for testing and reporting of data for inorganic repair materials

- Repair Material Description
- Composition
- Material Properties (22)
- Packaging and Storage
- How to Use the Material
Dimensionally Compatible Repairs

Properties in Order of Relative Importance

- **Restrained Shrinkage (ASTM C1581)**
  - No cracks within 14 days

- **Unrestrained Shrinkage (ASTM C157)**
  - 0.04% max. (28-days); 0.10% max. (ultimate)

- **Direct Tensile Strength (CRD-C 164)**
  - 400 psi min.

- **Modulus of Elasticity (ASTM C469)**
  - $3.5 \times 10^6$ psi max; similar to substrate (structural)

- **Thermal Coefficient (CRD-C 39)**
  - 7 millionths/°F max.

- **Compressive Strength**
  - Similar to substrate
Looking Back

We Have Come A Long Way!